PRESSURE MEASURING TESTS

SERIES A - RICH LIGHTS
SERIES B - BARCLAY

Brown & Williamson Tobacco Co.
1600 W. Hill St.
Louisville, Ky. 40201

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2023100024

Source: https://www.industrydocuments.ucsf.edu/docs/yrkm0000

Report Summary

Objective. The purpose of these tests was to determine the pressures exerted on the surface of a cigarette filter (i) by human lips in normal smoking conditions and (ii) by three types of filter-holders; the Cambridge, Filtrona, and Borgwaldt holders.

Method. To measure surface pressures a special measurement system was developed. A small (~ 1 to 2 mm dia.) latex bulb was mounted directly onto the filter and attached via a short section of hypodermic needle tubing and a teflon catheter to a low compliance pressure transducer. The entire system was filled with water to avoid the effects of air compression, and calibrated prior to each series of measurements.

Lip pressures were measured on twelve subjects during normal smoking. From 8 to 12 measurements were made on each subject, 5 with the sensing bulb positioned against the upper lip, and 5 with the bulb against the lower lip. The transducer output was observed on an oscilliscope and the maximum reading for each puff was recorded. Three average pressures were computed for each subject: upper lip average, lower lip average, and overall average.

Filter-holder pressures were determined by adjusting the cigarette position within the holder until the maximum reading was achieved. An average reading was determined for each of the three filter holders.

Conclusions. Results of this study indicate that human lips exert an average pressure of about 34 torr. Each of the three filter holders exert greater pressures as follows: Cambridge, 1.4 times as large as the average lip pressure; Borgwaldt, 3.5 times as large; and Filtrona nearly

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15 times as large. It follows, then, that the Filtrona holder represents the poorest approximation to human lips while the Cambridge holder is the closest, given the three classes of holders tested.

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Introduction

Tests were conducted to determine the pressures exerted on the surface of a cigarette filter by human lips and by several types of filter-holder: the Cambridge, Borgwaldt, and Filtrona holders. Measurement of surface pressure on a small portion of the filter surface necessitated the development of a special measurement technique. With this technique, a small, very compliant latex rubber bulb is attached to the cigarette surface and connected via stiff tubing to a low compliance pressure transducer. This entire system (bulb, tubing, and transducer) is filled with water to minimize the change in volume of the latex bulb during compression.

When lips or a filter-holder come into contact with the bulb, the external forces cause pressure inside the bulb to rise. As long as the bulb remains partially inflated, the pressure sensed by the transducer reflects the pressure applied to the bulb surface. Due to the low compliance of the water-filled system, the contained volume of the bulb changes very little, even for surface pressures approaching 500 torr. Since the test probe is so small, the normal contour of the lips and of the filter holders is minimally affected.

Measurement Apparatus

The complete measurement system is shown schematically in Fig. 1. The latex test probe (~ 1 to 2 mm dia) is secured using a contact adhesive to a small (~ 2 mm dia) exposed portion of the cigarette,

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approximately 7 to 9 mm from the filter tip. The sensing bulb slides over the end of a 1 cm length of 22 gage hypodermic needle tubing which is glued to the filter paper. The needle tubing attaches to a 2 ft. length of teflon catheter (~ 1 mm I.D.) which leads to the low compliance ($< 10^{-9}$ $cm^3/dyne/cm^2$) pressure transducer (Gould Statham P 23 Series). The output of the transducer is amplified using a variable gain low-noise amplifier and displayed on an oscilliscope.

Because the bulb had a non-linear response to contact pressure, it was necessary to calibrate each instrumented cigarette. This was accomplished using the calibration device shown in Fig. 2, consisting of a thin-walled latex tube mounted within a rigid plexiglas enclosure. This geometry was chosen for its close resemblance to the lip configuration. Pressure to the calibration device was controlled using a 10 psig pressure regulator and measured by a mercury manometer. When pressurized, the tube exerted a measured contact stress on the cigarette filter.

Test Procedure

a) Filter-holder measurements. The test probe was placed on the cigarette filter and calibrated over the range of anticipated pressures using the device described above. Filter-holder pressures were then measured using each of the following:

Cambridge holder. The latex sheet used in this test was the industry standard, 0.20-0.23 mm thick with a 3 mm dia hole. When stretched onto the holder, the latex hole diameter increased to 3.9 mm.

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Borgwaldt holder. The standard latex rubber sleeve was used which has a 7 mm O.D. with a wall thickness of 0.36-0.43 mm.

Filtrona. A latex sleeve of 6 mm O.D. and 0.38 mm wall thickness was used. The sleeve used was provided by R.J. Reynolds.

In each case, several pressure measurements were made at or near the position of peak pressure. The average values of pressure determined for each series of measurements were as follows: Cambridge; $\bar{p}$ = 47 torr, Borgwaldt; $\bar{p}$ = 118 torr, and Filtrona; $\bar{p}$ = 500 torr.

b) Human lip-pressure measurements. Prior to each test, a probe was mounted on a fresh cigarette and calibrated over the range of anticipated pressures, typically up to 250 torr. Occasionally the baseline would drift during the course of calibration indicating a leak in the system. When this occurred, the leak was repaired before measurements were made.

When the cigarette was calibrated, the subject was brought into the testing room and seated comfortably at a table. The subject was then instructed to insert the cigarette so that the sensor was centered on their lip and to smoke in a normal fashion, at a normal pace. In the first six tests the subject was asked to smoke with the bulb against the top lip for the first 3 to 5 puffs, then against the bottom lip for the remaining 3 to 5 puffs. In the last 7 tests, the procedure was reversed; first the bottom lip, then the top.

For each puff, the pressure excursions were observed on an oscilliscope screen and the peak excursion during each puff was recorded. Each individual had a unique pressure trace, the shape of which was fairly consistent. Typically, the pressure would rise rapidly to a first maximum as the lips

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contacted the probe, then fall to a lower value, then rise to a second maximum before falling to zero. This same general pattern can be seen in the sample traces of Fig. 3.

At the end of each session, the subject was questioned concerning the location of the probe and their general impressions during the test. The information thus obtained helped us to refine the technique in subsequent tests.

Test Results

Twelve subjects were tested using the procedure described above. The results for the first subject, however, were omitted from the study for the following reason. As a result of the mounting procedure, much of the filter cover had been removed, leaving large sections of the filter exposed. Consequently, the subject needed to draw much harder than normal in order to get enough smoke, causing pressures in excess of 300 mm Hg. In all subsequent tests, only a small section of filter paper was removed. To compensate in part for the added ventillation, the vent holes in the filter were taped closed. A second subject (subject 7) was re-tested because a pin-hole had inadvertently been made in the cigarette paper during probe mounting. Only the second set of data was used. Subject 9 was tested twice to examine the consistency of our measurements; both sets of results are presented.

The raw data for all tests are presented in Appendix A including the individual calibration curves. These results are summarized in Table 1 in terms of:

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(i) pressure developed during lighting, p_L;

(ii) mean upper-lip pressure, p_u;

(iii) Mean bottom-lip pressure, p_b; and

(iv) overall mean lip pressure, $\bar{p}$.

The mean value and standard deviation of each parameter is given in Table 1 for all subjects. A graphical representation of the results is shown in Fig. 4 including the pressures exerted by each of the three filter-holders tested. As seen in the figure, the Cambridge holder exerts pressures only slightly higher than the mean lip pressure, the Borgwaldt exerts a pressure about 3.5 times as great, and the Filtrona creates a surface pressure 15 times as great. Among the three filter holders tested, the Cambridge holder most closely approximates the pressure level produced by human lips.

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Table 1. Data Summary

Filter holders:

Cambridge - $\bar{p}$ = 47 torr (2 measurements)
Borgwaldt - $\bar{p}$ = 118 torr (3 measurements)
Filtrona - $\bar{p}$ = 500 torr (15 measurements)

Lip-pressures

Subject	Upper lip (p_u)	Bottom lip (p_b)	Overall ($\bar{p}$)	Lighting (p_L)
1	(no useful data -- see text)			
2	87	110	98.5	100
3	40	16	28	53
4	2.5	2.9	2.7	13
5	60	71	65	100
6	53	6.0	29	11.3
7	57	3.9	30	10[a]
8	88	4.4	46	3.4[a]
9A	10) 7.5	16) 13.2	13) 10.4	8.8[a]) 13.2
9B	5.1	10.4	7.8	17.5[a]
10	16.7	15.5	16.1	12.5[a]
11	51.3	3.3	27.3	3.8[a]
12	18	25	21.5	7.5[a]
Average (s.d.)	43.7 (29.7)	24.7 (34.4)	34.2 (32.9)	55 (44.0)/8.4 (4 29.8 (37.2)[b]

(a) Lighting with bulb on lower lip

(b) Upper lip/Lower lip. Overall average directly below.

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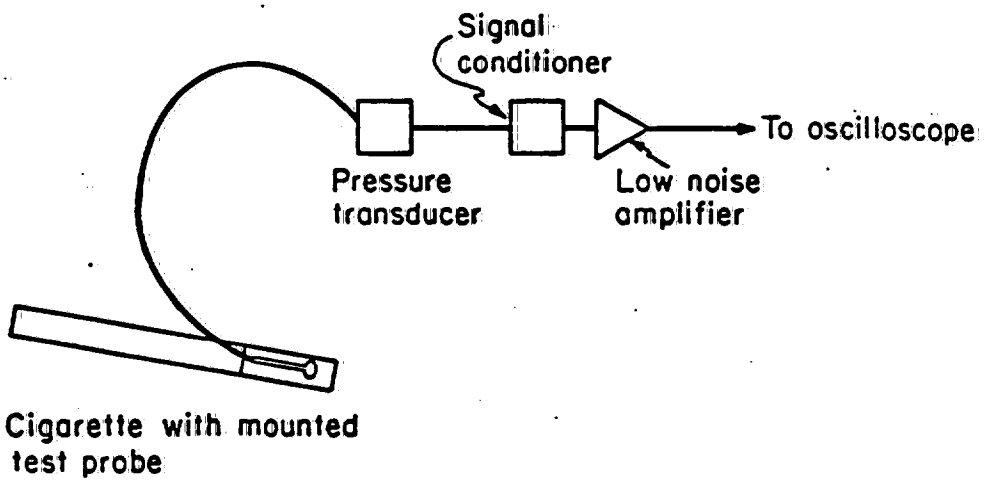

Figure 1(a). Schematic of test apparatus.

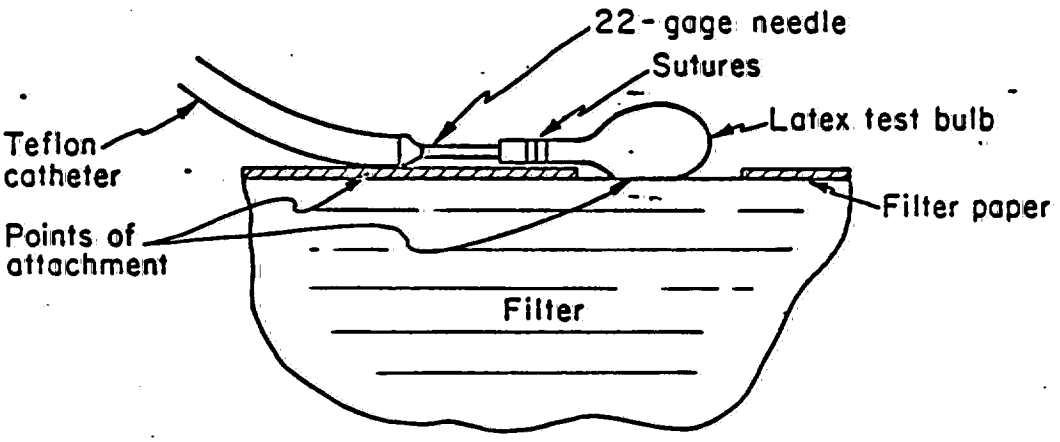

Figure 1(b). Detailed sketch of test probe.

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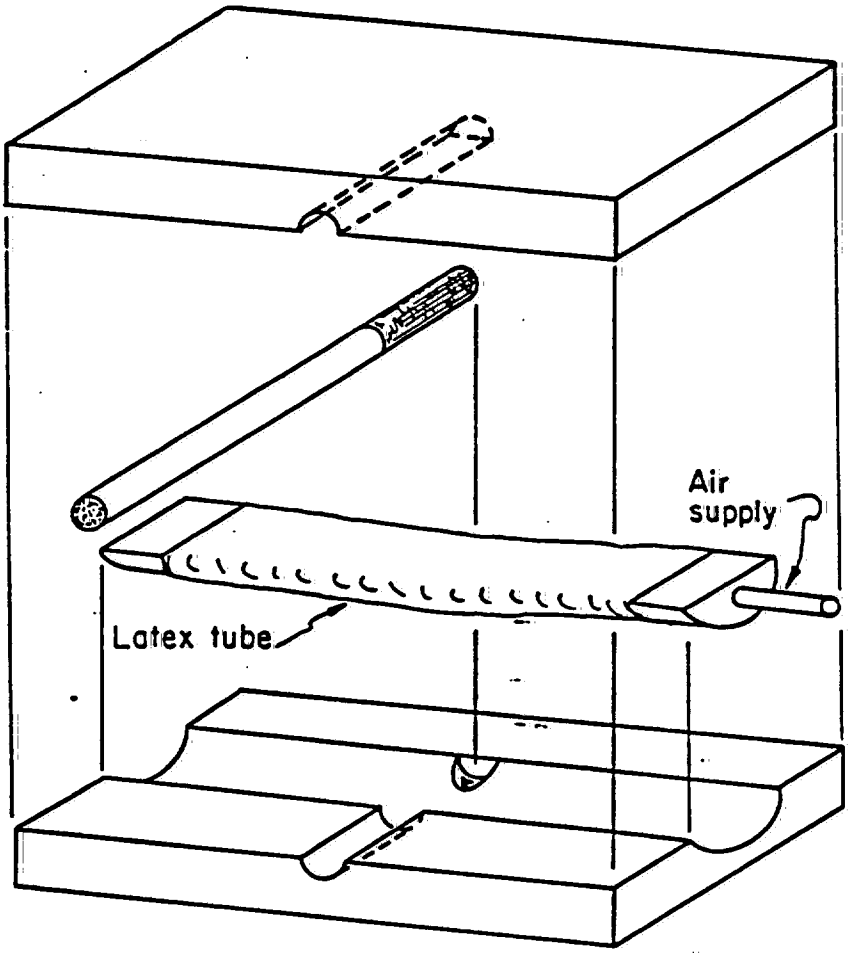

Figure 2. Assembly drawing of calibration device.

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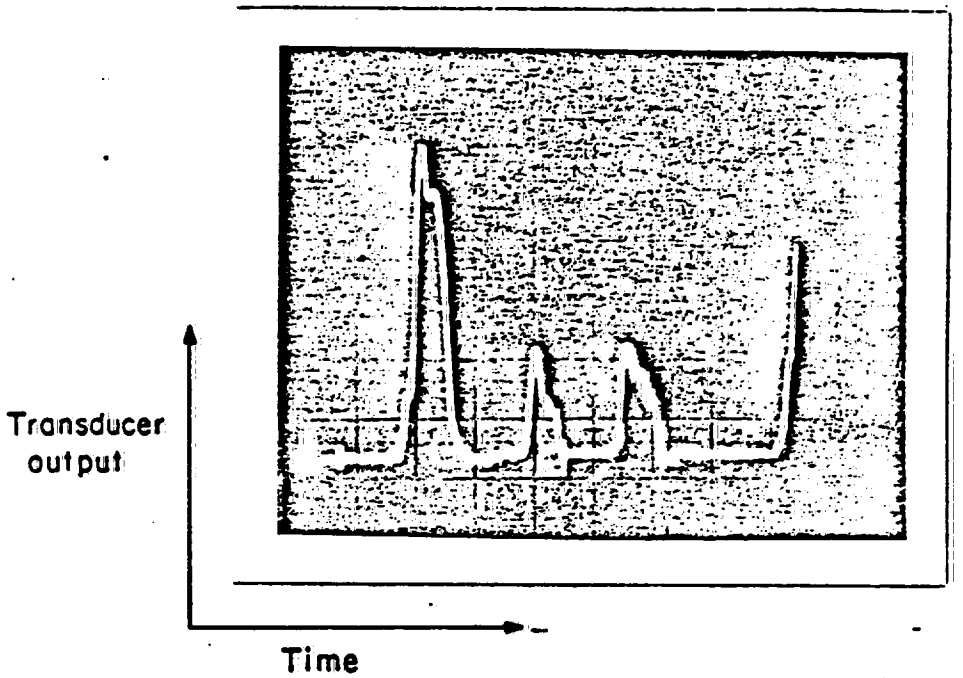

Figure 3. Three puff profiles as recorded on the oscilliscope.

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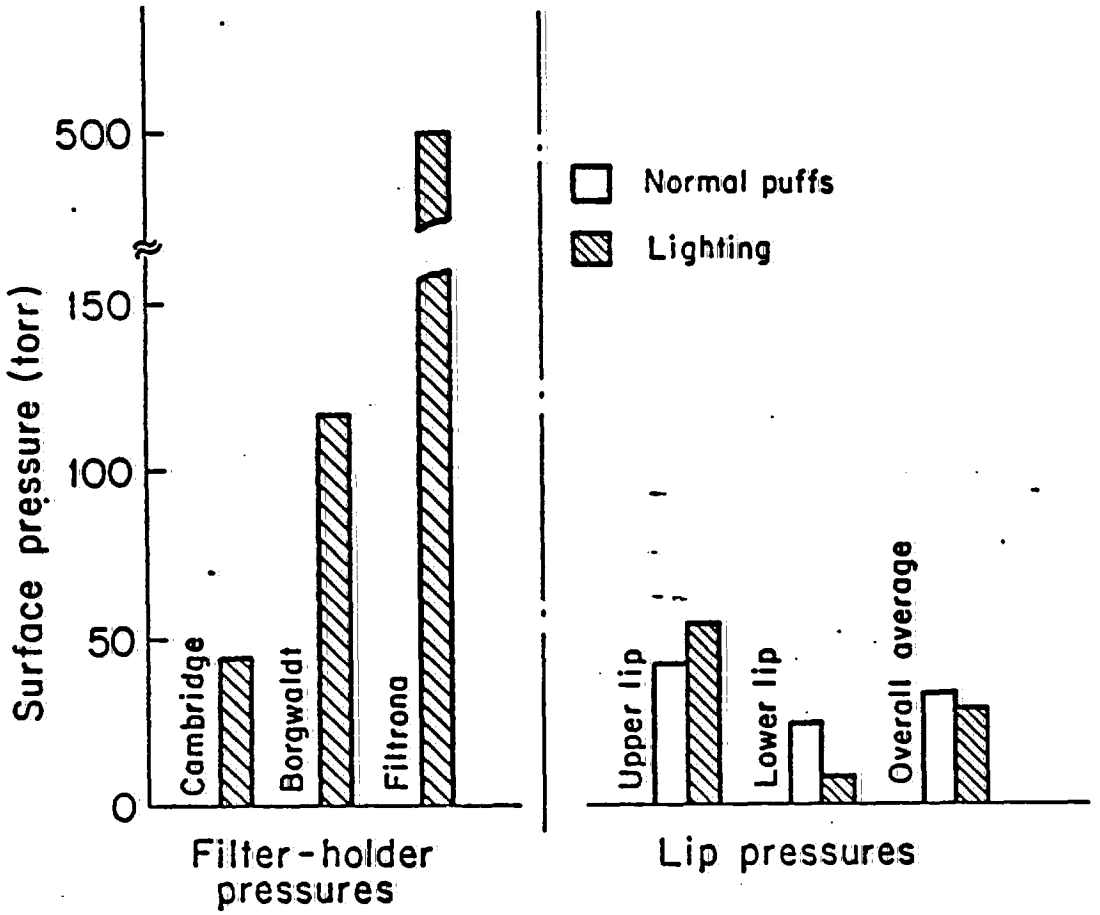

Figure 4. Summary of Test Data.

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APPENDIX A

EXPERIMENTAL DATA

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Test Data Sheet

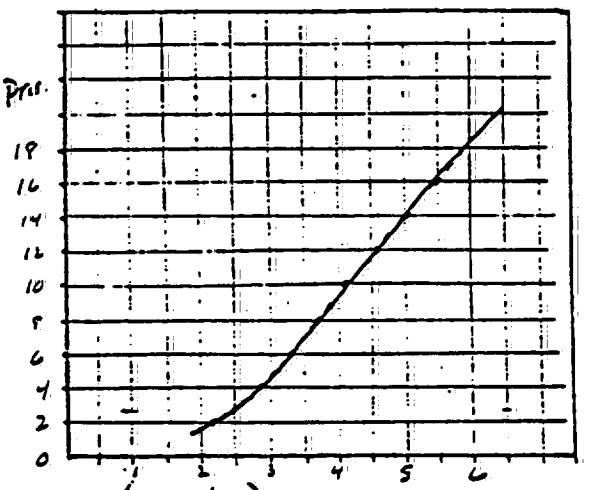
Date 5-30 Time 5:10 Subject # Holders Sex —

Weight Cambridge Filtrona Height ____

Comments _____

CALIBRATION

Pressure (in Hg)	Output voltage (0.5v/cm)
0	0
2	2.2
4	2.8
6	3.3
8	3.7
10	4.1
12	4.6
14	5.0
16	5.5



TEST RESULTS

Measurement #		Maximum scale reading (0.5v/cm)	Photograph	Pressure
1	Borgwaldt (7mm OD tube)	3.0 ~125 torr		4.7 } = 115
2		3.0		4.7
3	Cambridge	2.0		1.7 } 43 torr
4		2.0 (2.3 max) ~46 torr		1.7
5				2.2 = 55 t
6	Filtrona ①	6.0 6.5		
7		6.3 6.3		
8	(6mm OD tube)	5.9		
9	②	6.8 6.1 Avg = 6.4		20 = 500 to
10	Filtrona	7.0 6.7		
		7.1 6.4 ~ 470 torr		
		7.1 6.2		
		6.4 6.0		

Test comments:

2023100038

Test run Ventilation pro

Too much exposed filter area

Test Data Sheet

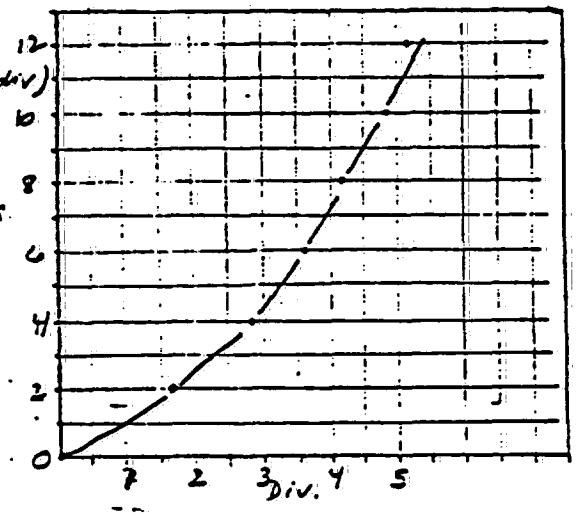
Date 5-30 Time 11:30 Subject # 1 Sex F

Weight _____ Height _____

Comments No photographs taken - probe read directly from scope.

CALIBRATION 0 0 V

Pressure (inches Hg)	Output voltage (0.5 V/div)
2	1.7 div
4	2.8
6	3.6
8	4.2
10	4.8
12	5.2



TEST RESULTS

Measurement #		Maximum scale reading	Photograph
1	Bulb on top throughout	6.5	
2		3	
3		6.5	
4		Off scale	
5		~7+	
6	Change scale p.d. V/div	7	
7		2	
8		6	
9		5	
10		4	
		5	
		5	

Put on more tape to reduce leakage into filter

Test comments:

Don't use

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Test Data Sheet

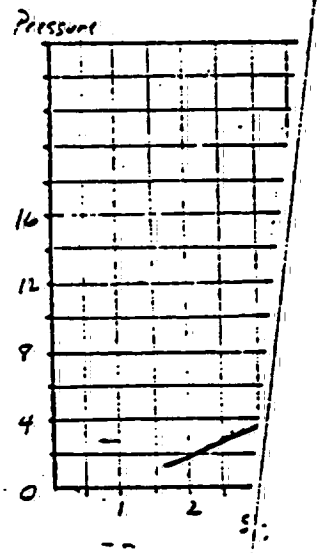
Date 5-30 Time 1:00 Subject # 2 Sex M

Weight _____ Height _____

Comments _____

CALIBRATION

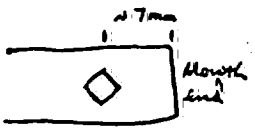
Pressure (in Hg)	Output ~~voltage~~ (volts/cm) cm
0	0
4	3.2
8	4.7
12	6.1
16	7.4



TEST RESULTS

Measurement #		Maximum scale rea
1	Lighting	3.2
2	Bed on top lip	2.0
3		2.8
4	↑	3.2
5	Bed on Bottom Lip ↓	2.8
6		2.4
7		4.2
8		2.0
9		4.2
10		

Test comments:



Now using a single window in tipping/plug wrap

Date

Commen

CALIBRA

Pressur

0
2
4
6
8
10
12
14

TEST RESULT

Measurement

1
2
3
4
5
6
7
8
9
10

Test comments:

7 m

2023100040

Test Data Sheet

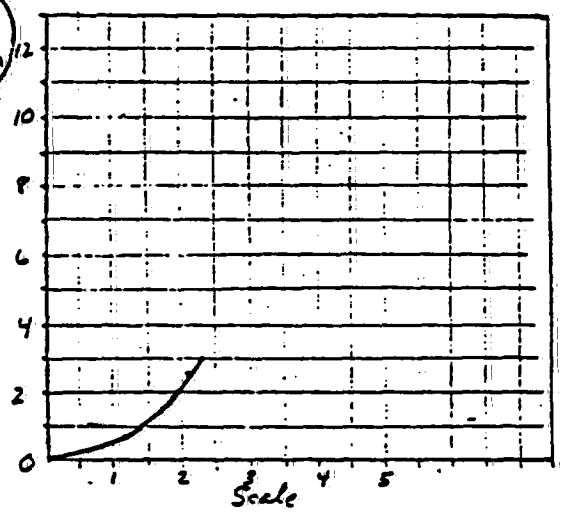
Date 5-30 Time 1:50 Subject # 3 Sex F

Weight _____ Height _____

Comments _____

CALIBRATION

Pressure (in Hg)	Output ~~voltage~~ (0.2v/cm) cm	P	O
0	0		
2	2.1	0	0
4	2.9	1.0	1.4
6	3.2	1.5	1.7
8	3.5	2.0	1.9
10	3.9	2.5	2.1
12	4.1	3.0	2.3
14	4.3		



TEST RESULTS

Measurement #		Maximum scale reading	" Hg	Torr	Photograph
1	Lighting	2.0	2.1	53	
2		2.0	2.1	53	
3		2.0	2.1	53	
4		1.0	0.6	15	
5	Bottom Lip	1.0	0.6	15	
6		1.0	0.6	15	
7		1.2	0.7	18	
8		1.2	0.7	18	
9		0.8	0.5	13	
10					

$p_L = 53$, $p_u = 40$, $p_B = 16$ $\bar{p} = 28$

Test comments:

7mm window position

2023100041

Test Data Sheet

Date _____ Time 2:45 Subject # 4 Sex F

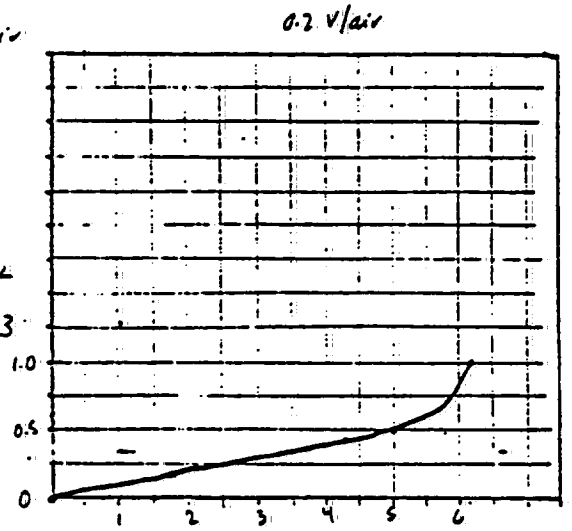
Weight _____ Height _____

Comments _____

CALIBRATION 1.0 V/div 0.2 V/div

Pressure		Output voltage		
0		0	0	
1	0	1.6	0	0
2		1.9		
3	0.5	2.1	0.5	5
4		2.3		
5	1.0	2.5	1.0	6.2
6		2.7		
7	0.45	2.9	0.45	4.3
8		3.1		
9		3.3		
10		3.4		
11		3.6		
12		3.7		

0.2 V/div



TEST RESULTS

Measurement #		Maximum scale reading		Photograph
			volts	bar
1	Lighting 1.0/div	1.0	0.5	13
2	0.5/div			
3	0.2/div	0.7	0.18	2.5
4		0.7	0.18	2.5
5		0.7	0.18	2.5
6	Bottom lip	1.0	0.15	3.8
7		0.7	0.10	2.5
8		0.6	0.12	3
9		0.3	0.08	2
10				

$p_L = 13$, $p_u = 2.5$, $p_b = 2.9$

$\bar{p} = 2.7$

Test comments:

Window / 7 mm

2023100042

Test Data Sheet

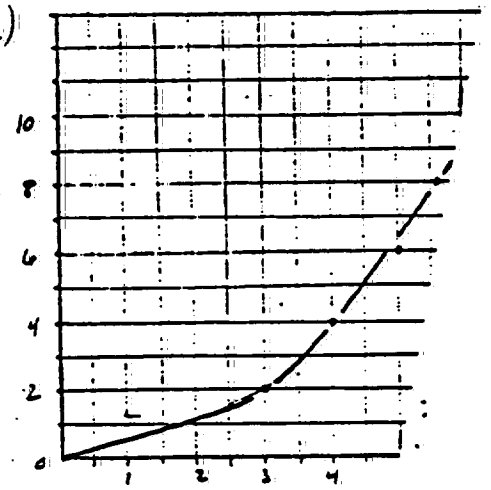
Date 5-30 Time 3:55 Subject # 5 Sex F

Weight _____ Height _____

Comments _____

CALIBRATION

Pressure (in Hg)	Output voltage (0.5v/in)
0	0
2	3.0
4	4.0
6	5.0
8	5.6
10	6.4
12	7.2



TEST RESULTS

Measurement #		Maximum scale reading	" Hg
1	Lighting	4.0	4
2		3.0	2
3		2.7	1.7
4		3.8	3.5
5		3.2	2.4
6	Bottom lip	2.9	2.9
7		3.9	3.8
8		3.3	2.6
9		2.9	2.9
10		3.0	2

$p_L = 100$ p_u

Test comments:

Window/7mm
Said felt normal, took normal puffs.
(a left sided smoker)

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Test Data Sheet

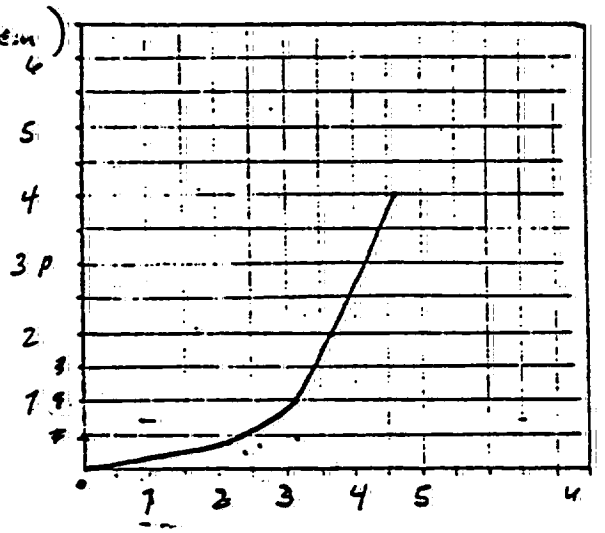
Date 5-30 Time 4:35 Subject # 6 Sex M

Weight _____ Height _____

Comments _____

CALIBRATION

Pressure (in Hg)	Output voltage
0	0
0.5	2.4
1	3.1
2	3.7
4	4.6
6	5.4
8	6.0
10	6.2



TEST RESULTS

Measurement #		Maximum scale reading	" Hg	Photograph torr
1	Lighting	2.3	0.45	11.3
2		3.4	1.5	38
3		4.2	3.1	78
4		3.7	2	50
5		3.6	1.9	45
6	Bottom	1.8	0.3	7.5
7		1.4	0.2	5
8		1.2	0.15	3.8
9		1.8	0.3	7.5
10				

$\bar{p}_L = 11.3$ $\bar{p}_u = 53$ $\bar{p}_b = 6.0$ $\bar{p} = 29.5$

Test comments:

Window / 7 mm

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DATA NOT USED

Test Data Sheet

Hole in Tob Suction Paper

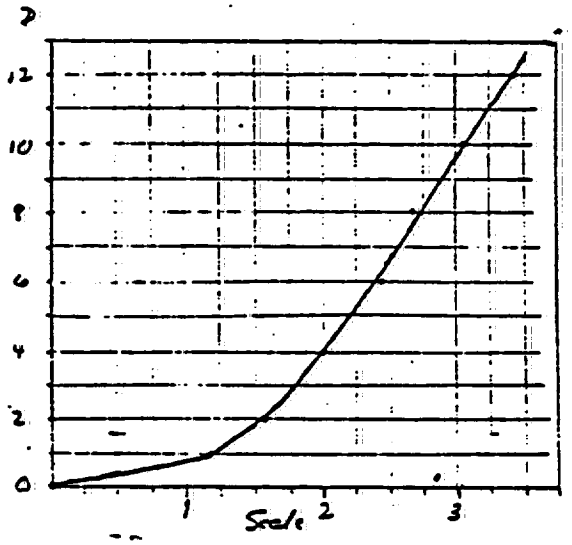
Date 5-31 Time 9:05 Subject # 7A Sex M

Weight _____ Height _____

Comments _____

CALIBRATION 0.5 v/cm

Pressure	Output voltage
0	0
1	1.2
2	1.6
4	2.0
6	2.4
8	2.7
10	3.1
12	3.4



TEST RESULTS

Measurement #		Maximum scale reading	Photograph
1	Lighting (Bottom)		
2	0.2 v/cm	0.5	
3		1.5	
4		0.8	
5		0.5	
6	(Top)	1.2	
7		0.8	
8		0.7	
9		0.5	
10			

Test comments:

Window 7mm

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Repeat

Test Data Sheet

Date 5-31 Time 10:10 Subject # 7 Sex M

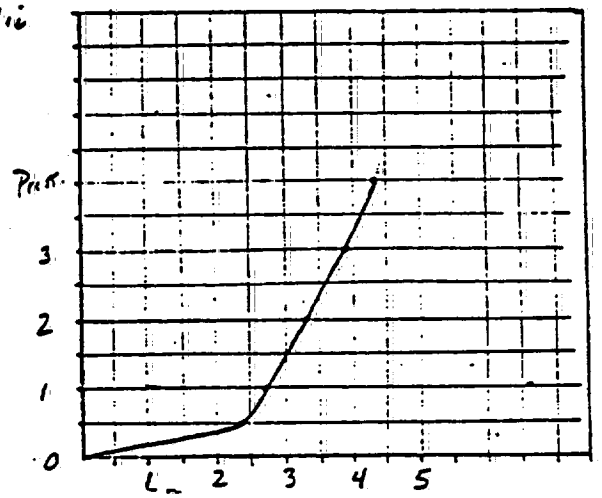
Weight _____ Height _____

Comments _____

CALIBRATION

.5 V/div

Pressure	Output voltage
.5	2.4
1.0	2.7
2.0	3.3
3.0	3.9
4.0	4.3
5.0	4.6
6.0	4.9
7.0	5.1
8.0	5.4
9.0	5.6
10.0	5.9



TEST RESULTS

Measurement #		Maximum scale reading		Photograph
1	Lighting	2.0	0.4	10
2		0.7	0.10	2.5
3	Scale 0.2 V/div	1.2	0.05	2
4		1.4	0.10	2.5
5		3.0	0.25	6.3
6		3.0	0.25	6.3
7	Top	6.0	10.2	255
8	0.5 V/div	2.2	0.45	11.3
9		1.2	0.25	6.3
10		1.2	0.25	6.3
		1.2	0.25	6.3

Test comments:

$p_L = 10$ $p_u = 57$ $p_E = 3.9$ $\bar{p} = 30$

Window / 7 min

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Test Data Sheet

Date 5-31 Time 9:30 Subject # 8 Sex F

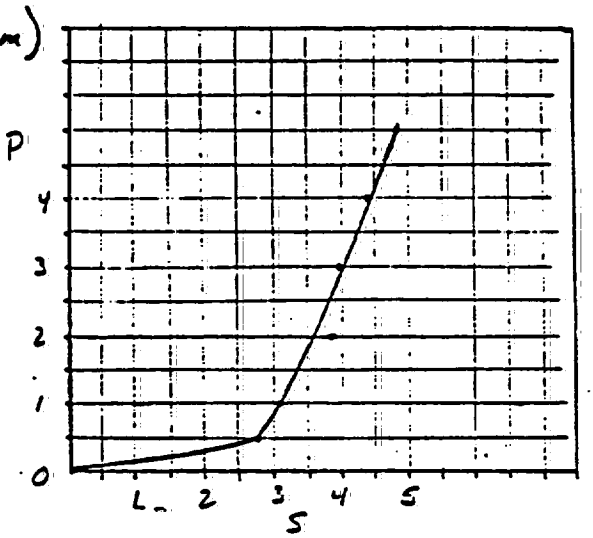
Weight _____ Height _____

Comments _____

CALIBRATION

(0.5v/cm)

Pressure (mHg)	Output voltage
0	0
0.5	2.8
1	3.1
2	3.8
3	3.9
4	4.4
5	4.8
6	5.1
7	5.4
8	5.8
9	6.1
10	6.6



TEST RESULTS

Measurement #		Maximum scale reading		Photograph
1	Lighting	0.8	0.15	3.4
2		0.7	0.12	3
3		1.0	0.19	4.5
4		1.2	0.20	5.0
5		1.2	0.20	5.0
6	Top	2.8	0.5	12.5
7		2.9	0.7	17.5
8		6.5	9.8	245
9		4.0	3.0	75
10				

$p_L = 3.4$ $p_u = 8.8$ $p_b = 4.4$ $\bar{p} = \cancel{5.0}\ 4.6$

Test comments: Window / 7mm

"Belt was puffing abnormally"

2023100047

Test Data Sheet

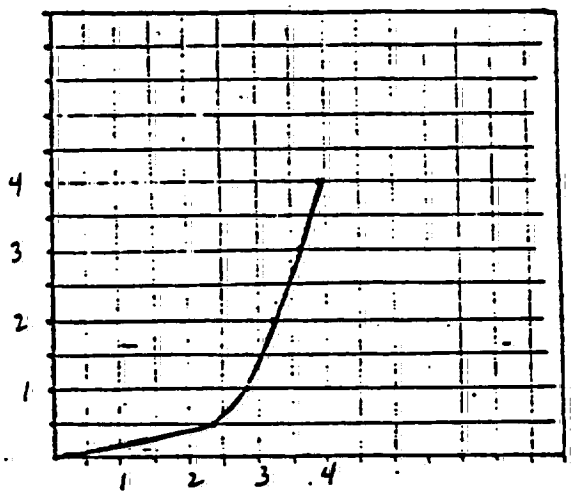
Date 5-3 Time 11:00 Subject # 9A Sex M

Weight _____ Height _____

Comments _____

CALIBRATION

Pressure (in Hg)	Output voltage (0.5v/cm)
0	0
0.5	2.4
1	2.8
2	3.2
3	3.6
4	3.9
5	4.2
6	4.5
7	4.6
8	4.9
9	5.2
10	5.4



TEST RESULTS

Measurement #		Maximum scale reading		Photograph
1	Lighting (Ex Hom)	2.6	0.7	17.5
2		2.3	0.95	24
3		1.4	0.3	7.5
4		1.5	0.25	6.3
5		0.7	0.15	3.8
6	Top	0.8	0.18	4.5
7		0.8	0.18	4.5
8		0.9	0.20	5.0
9		1.2	0.23	5.8
10		1.2	0.23	5.8

$p_L = 17.5$, $p_u = 5.1$, $p_b = 10.4$, $\bar{p} = 7.8$

Test comments:

Window / 7mm

2023100048

Source: https://www.industrydocuments.ucsf.edu/docs/yrkm0000

Repeat

Test Data Sheet

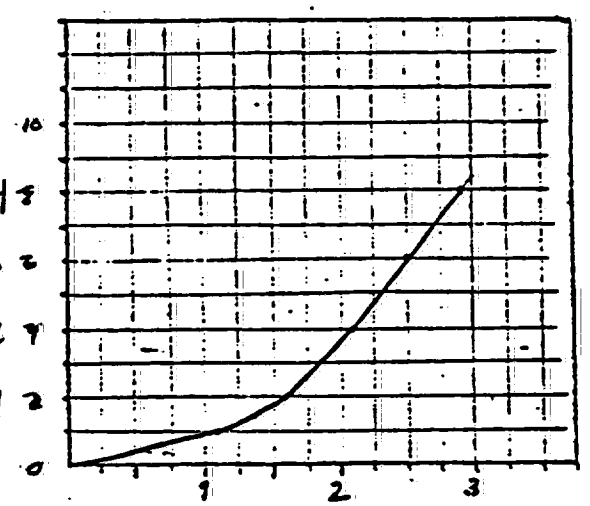
Date 5-31 Time 12:00 Subject # 9B Repeat Sex M

Weight _____ Height _____

Comments _____

CALIBRATION

Pressure (in Hg)	Output voltage (0.5 v/cm)
0	0
0.5	1.1
1	1.6
2	2.1
3	2.5
4	2.9
5	3.1
6	3.4
7	3.7
8	4.0
9	4.3
10	4.5



TEST RESULTS

Measurement #		Maximum scale reading		Photograph torr
1	Lighting (bottom)	0.8	0.35	8.8
2		1.0	0.45	11.3
3		1.4	0.75	18.8
4		1.4	0.75	18.8
5		1.2	0.60	15
6	Top	1.0	0.45	11.3
7		0.8	0.35	8.8
8		0.8	0.35	8.8
9		1.0	0.45	11.3
10		0.9	0.40	10

$p_L = 8.8$, $p_u = 10.0$, $p_b = 16.0$, $\bar{p} = 13.$

Test comments:

[illegible] / [illegible]

2023100049

Test Data Sheet

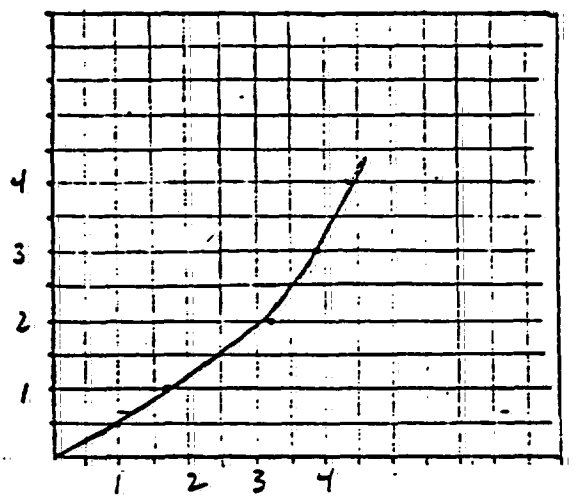
Date 5-31 Time 11:30 Subject # 10 Sex F

Weight _____ Height _____

Comments _____

CALIBRATION 0.5v/div

Pressure	Output voltage
0	0
.5	1.0
1.0	1.7
2.0	3.2
3.0	3.9
4.0	4.3
5.0	4.5
6.0	5.0
7.0	5.3
8.0	5.6
9.0	5.8
10.0	6.0



TEST RESULTS

Measurement #		Maximum scale reading		Photograph
1	Lighting (Bottom)	1.0	0.5	12.5
2		1.1	0.6	15
3		1.1	0.6	15
4		1.1	0.6	15
5		1.2	0.68	17
6	Top	1.1	0.6	15
7		1.0	0.5	12.5
8		1.2	0.68	17
9		1.7	1.0	25
10		1.3	0.75	19
		1.2	0.68	17
		0.9	0.45	11.3

Test comments:

Window / 5mm

$p_L = 12.5$, $p_u = 16.7$, $p_b = 6.5$

$\bar{p} = 16.1$

2023100050

Source: https://www.industrydocuments.ucsf.edu/docs/yrkm0000

Test Data Sheet

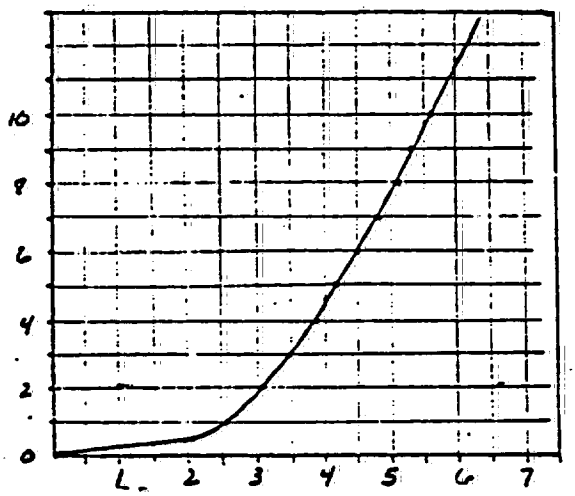
Date 5-31 Time 12:55 Subject # 11 Sex F

Weight _____ Height _____

Comments _____

CALIBRATION

Pressure (in Hg)	Output voltage (0.5v/cm)
0	0
0.5	2.1
1	2.6
2	3.1
3	3.5
4	3.9
5	4.2
6	4.5
7	4.8
8	5.1
9	5.3
10	5.6



TEST RESULTS

Measurement #		Maximum scale reading		Photograph
1	Lighting (bottom)	0.8	0.15	3.8
2		1.0	0.17	4.3
3		0.6	0.10	2.5
4	Change scale 0.2V/div	1.3	0.08	2
5		2.5	0.17	4.3
6	Top	3.0	0.20	5.0
7		4.5	0.4	10.0
8		5.2	0.5	12.5
9		7.5	1.9	47.5
10	0.5 V/div	4.2	5	125
		4.0	4.3	108

Test comments:

p_L = 3.7, p_L = 3.3 p_u = 51.3 $\bar{p}$ =

2023100051

Source: https://www.industrydocuments.ucsf.edu/docs/yrkm0000

Test Data Sheet

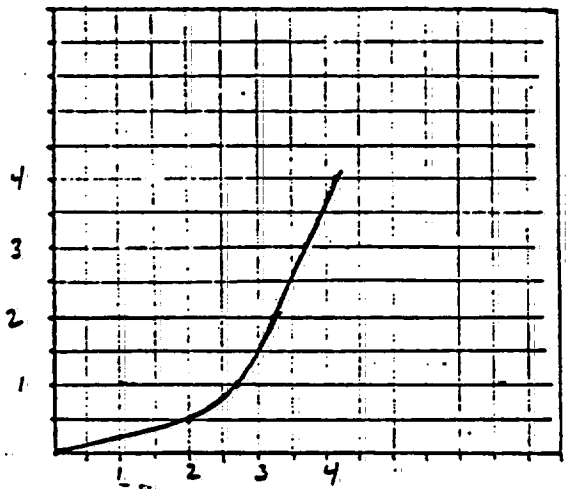
Date 5-31 Time 1:40 Subject # 12 Sex F

Weight _____ Height _____

Comments _____

CALIBRATION

Pressure (in Hg)	Output voltage 0.5 V/cm
0	0
0.5	2.0
1	2.7
2	3.2
3	3.7
4	4.1
5	4.4
6	4.8
7	5.1
8	5.4
9	5.7
10	6.0



TEST RESULTS

Measurement #		Maximum scale reading		Photograph
1	Lighting (Bottom)	1.2	0.3	7.5
2		3.2	2	50
3		1.5	0.4	10
4		2.2	0.6	15
5	Top	1.8	0.5	12.5
6		2.9	1.3	33
7		1.8	0.5	12.5
8		1.9	0.55	13.8
9				
10				

$p_L = 7.5$, $p_u = 18.0$, $p_b = 25$, $\bar{p} = 21.5$

Test comments:

[illegible]

2023100052